Comparative Evaluation of Energy Efficiency of Brick Kilns and Energy Study of Natural Gas Based Brick Kiln for Small Scale Production in India

Ph. D Synopsis

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1 Research Area:	**Energy efficiency in Brick Kiln**
2 Topic of Research Work:	**Comparative Evaluation of Energy Efficiency of Brick Kilns and Energy Study of Natural Gas Based Brick Kiln for small scale production in India.**

3 Introduction:

3.1 Background:

Development in any country is majorly depended on its infrastructure. In developing India construction sector estimated to grow at a rate of 6.6% per year between 2005 and 2030 [1] resulting an upcoming increased demand for building materials. India stands second in the production of clay fired bricks, with more than 10 percent share of global production [2] represents its wide application. In India there is more than 100,000 brick kilns, producing about 150-200 billion bricks annually [3].

3.2 Scale and industry type:

In India Bricks making is a small-scale, traditional industry located in the rural and semi-urban areas in the form of clusters having high density up to hundred kilns employing around 10 million workers. Brick Kilns do not operates during the rainy season. Workers involved in these kilns are from backward and poor regions works in harsh, low paying conditions with their families, including young children in lack of basic facilities.

3.3 Fuel consumption:

Brick Kiln operates between a temperature range of 700 -1100 ^{o}C, requires a large amount of fuel per year and is among the highest industrial consumers of coal (roughly 30-35 million ton) in the country [4].

3.4 Environmental Emissions:

One of the major activities of brick manufacturing is the combustion of fuel and as a result huge pollution is emitting into the atmosphere (Environment Protection Authority 1998). An upcoming increased demand the clustering of brick kilns has given rise to environmental concerns. Use of coal and other biomass fuels in brick kiln results in the emissions of carbon dioxide (CO2) particulate matter (PM), including black carbon (BC), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), and carbon monoxide (CO), which makes a negative effect on the health of workers and population nearby area. The total CO_2 emissions are estimated to be 41.6 million tonnes and it accounts for about 4.5% of total GHG emissions from India [5]. Now a day high cost and lack of good quality coal have resulted in an increased use of high-sulphur coal and loose biomass fuels which are increasing the emissions.

3.5 Topsoil:

By the use of good quality agriculture topsoil for brick production nearby area suffers from land degradation. The industry is estimated to consume 350 million tonnes of top soil every year [5]. Some clay minerals are hydrated aluminum silicates that are usually found from the weathering of rocks [6]. Clay characteristics may even affect the quality of the bricks.

3.6 Industrial challenges:

Production process is very traditional and bricks are mainly produced through manual processes with little knowledge on raw material (mainly clay) and its selection. Currently the brick production in India takes place in small units, using manual labour, sun drying and traditional firing technologies.

In spite of a large consumption in construction sector, its importance in the livelihoods of the poor, its large consumption of coal, and its impact on health and environment, this sector has seen a very few development for improvement. Industrial challenges like manual operation, major dependency on workers,

increase in wages of skilled labor, limited availability and increasing rate of good quality coal, shortage of good quality clay, etc. demands a need of upgradation in technology in terms of operation, working conditions, firing technology, fuel and raw material.

Initiatives that have been undertaken are listed in Table-1. The most significant government interventions were the environmental regulations enacted in the 1990's, which resulted in upgradation in the firing technology from moving chimney bull trench kilns to fixed chimney bull trench kilns.

Table-1: Development Programmes/Initiatives in the Indian Brick Industry

	Agency/ Programme	**Type of Intervention**	**Impact**
1970's	Central Building Research Institute, Government of India	**Technical**: Introduction of Zig-zag firing technology and semi mechanization Process	• Successful in seeding the technologies. • No large-scale adoption.
1990's	Central Pollution Control Board/ Ministry of Environment and Forest (MoEF)	**Regulation:** Air emission regulation for brick kilns	• Large-scale shift (around 30,000 kilns) from moving chimney Bull's Trench Kiln technology to more efficient and less polluting fixed chimney Bull's Trench Kiln technology.
1995-2004	Swiss Agency for Development and Cooperation	**Technical**: Introduction of Vertical Shaft Brick Kiln (VSBK) Technology	• Successful in seeding the technology. • No large-scale adoption.
2009-ongoing	United Nations Development Program - Global Environment Facility (UNDP-GEF)	**Technical**: Introduction of hollow bricks and other Resource-efficient bricks.	• Not known

Upgradation of technology for producing Energy–efficient bricks would require better and improved understanding and knowledge on various aspects of raw materials and its preparation. Introduction of machinery would require better understanding on the drying processes. Significant knowledge and skills at various levels of the industry (workers, operators and entrepreneurs) are required for improving yield and reducing breakage in brick making. Technology upgradation in the sector would open up new sets of opportunities of employment in the brick sector which would lead to improved livelihoods for the workers. Promotion of technology upgradation in the small scale brick sector would lead to modernization of the industry.

4 Problem Statement:

Indian brick industry consists of large number of small brick kiln units scattered across various clusters in different parts of India. Since the brick kiln units are not recognized as an industrial setup, they face several issues like non-availability of resources (e.g. good quality coal, soil, etc) and meeting the existing regulations.

One of the regulations of the government stipulates use of flyash in brick making. This would require significant changes and upgrade in existing setup of brick making processes for which ready-made solutions are not available. Use of obsolete technologies and use of solid bricks with traditional practices are seen as major threats to Indian brick industry.

Limited availability of information on technologies, no proven & operating modern brick kiln units at cluster levels, non-availability of trained manpower, limited access to finance, unexplored market for other building products and old specifications & codes for building materials and non-availability of organized program & institutional mechanism have been identified as problems in Indian brick industry. Under the business as usual scenario Indian brick industry will continue to operate with traditional technologies and practices. With its poor efficiency levels, the brick industry will be consuming about 30-35 million tonnes of coal every year, producing about 42 million tonnes of CO_2 every year (4.5% of total emissions from India), which is a global threat.

Hence, there is a great need to find an alternate kiln solution with high in efficiency, qualitative in production and low in GHG emission.

5 Scope of the research work:

The brick sector is one of the most polluting industries in India and the Government of India has enforced air emission standards for brick kilns. These regulations were notified by the MoEF (Ministry of Environment and Forests) during 1996 aiming at controlling air pollution from brick kilns. The notification also banned the use of moving chimney type Bull's Trench Kilns (BTKs), switch over to fixed chimney system and adoption of pollution control system (gravity settling chamber) in brick industries.

One of the positive impacts of the enforcements was the Indian brick industry started looking forward to local technological solutions to meet these needs. These efforts had led to the development of three prominent fixed chimney designs (Central Building Research Institute, Punjab State Council for Science and Technology and Aligarh Muslim University) in the country. The regulations also brought in certain awareness on pollution control and energy conservation among the brick industries. One such programme is supported by the Swiss agency for Development and Cooperation (SDC) and executed through NGOs, focuses on capacity building of brick firemen community in India.

Another environment related regulation on the use of fly ash in brick making was notified by MoEF during 1999. This regulation aims at conserving the top soil through increased use of fly ash from coal based thermal power stations in brick making. The implementation and monitoring of the regulations are being carried out through Central Pollution Control Board (CPCB), state level pollution control boards and district level offices. Fly ash is a partial replacement for top soil used in brick making. Use of fly ash in brick making is not applicable to brick kiln units that are located beyond a radius of 100 kilometers from coal–based thermal power stations. However, preservation of top soil is vital for agricultural–based economies like India.

Production of energy-efficient bricks and large scale adoption in construction would ensure reduction in overall consumption of top soil by individual brick kiln units. Production and use of energy–efficient bricks (hollow blocks and perforated bricks) on a large scale would help in reducing the rate of consumption of top soil (up to 30%).

6 Objective of research work:

The goal of the research work is to reduce energy consumption, and reduce GHG emissions by development of small scale Gas fired kiln technology for production of energy efficient bricks in India.

The proposed work aims to carry out a comprehensive assessment of brick making technologies to gain a deeper understanding of the energy utilization and emissions from current technologies as well as technologies that offer the promise of cleaner brick production. A comparative evaluation of different types of Brick Kiln technologies will be carried out depending upon various parameters like Energy performance, Environment performance, fuel used, production capacity, quality of the product, functioning etc. It is also proposed to carry out a brief study of natural gas bases tunnel Type brick kiln on the basis of the green house gas emission and the specific energy consumption by the bricks.

A model of the gas based brick kiln will be developed. On the basis of the performance of this kiln a comparative study of the results will be carried out in specific respect to the green house gas emission and energy consumption. Work aims at the identification of the most efficient and minimum polluting alternative Kiln technology in Indian context. The results can also be used as inputs in a parallel study undertaken to assess multiple types of walling materials, including clay fired bricks.

7 Methodology of research work:

For carrying out this work the methodology employed shall be as follows:-

- **i.** Literature survey.
- **ii.** Identification of the location (Cluster near the region of Taj Trapezium Zone) and perform the study of different given parameters of the brick kilns which are operating with coal and other bio fuels like husk etc.
- **iii.** Development of a model of Natural gas based Tunnel type kiln.
- **iv.** Experimental investigation of Kiln performance using Natural gas as a fuel.
- **v.** Comparative study and analysis of the kiln performance using the natural gas as a fuel.
- **vi.** Analysis of the results on the basis of the energy efficiency and green house gas emissions.
- **vii.** Impact of the result obtains on the Kiln Industry and environment.

The experiments are proposed to be conducted on a model of natural gas based tunnel type brick kiln for the small scale production capacity of up 25000 of bricks/day. The load variation of the kiln will be made by changing type of the bricks (Regular clay bricks, 30% flyash mixed bricks and different types of hollow bricks) and their dimensions. Exhaust gas analysis will be carried out for the different type of charge being used in the Kiln. Other performance parameters as needed for analysis shall be estimated. Conclusion drawn from the comparative evaluation of performance using various bricks and fuels shall be immense importance for academic and Kiln Industry.

8 The testable model of Natural Gas based Tunnel Kiln:

Various types of brick kilns are in operation throughout the world. Tunnel kiln is the most widely used technology in developed countries as it is highly automated.

In this research work we will develop a model of natural gas based tunnel type kiln. The idea of a typical Tunnel kiln layout geometry is taken from local brick/ceramic industries of nearby areas. To produce certain quality bricks/ceramics, a particular temperature distribution throughout the kiln needs to be maintained.

Selection of various optimized design parameters will be obtained through the study about the past performance of the different size of tunnel type kilns, their production capacity, and efficiency.

The total length of the tunnel can be divided into pre-heating, firing and cooling zones. Green bricks pass through the pre-heating, then firing and finally the cooling zones, while fresh air flows in opposite direction of the brick stack move.

The design parameters that need to be played around are gas and air flow rates, flow directions, their inlet-outlet number, spacing and placements at different locations etc. Other important parameters that are varied include brick stack placement with respect to air and gas inlet-outlets, gaps between kiln roof and stacks and gaps between two consecutive stacks.

To supply adequate air, a large size of air inlet can place at the roof of the exit end of the kiln. To maintain the air temperature distribution as, one intermediate size air outlet and small air (openings) can also place at the roof of the kiln in the cooling zone. All these heated air can transfer to dryer to dry the green bricks.

The Tunnel kiln geometry is given below based on industrial knowledge obtained from field visit.

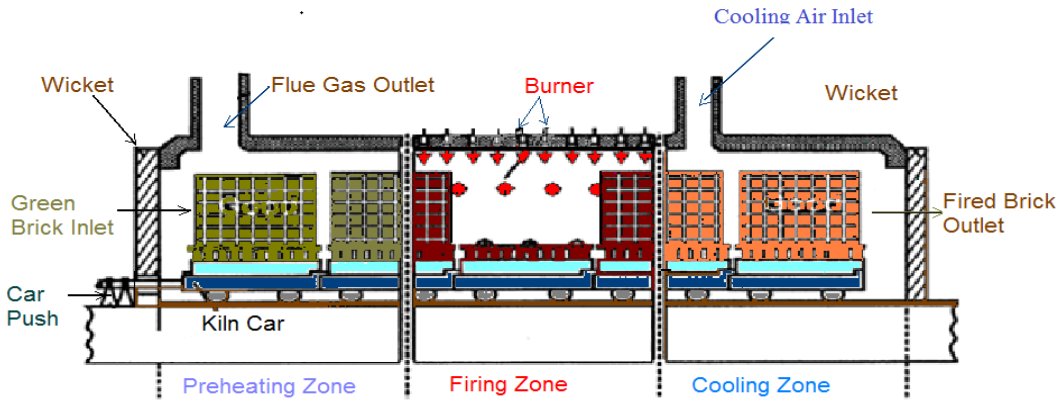

Figure - 1: Tunnel kiln

9 Kiln Performance related data to be monitored:

The data involved in the research are proposed to be monitored and recorded. The following quality control measures will be followed to increase the reliability of the data monitored. We will monitor the data on the basis of fuel consumption, brick production and weight of the bricks, emissions.

Table-2: List of Technical Measurements

	Data Type	**Data Units**	**Principle of Measurement**	**Sample Location**	**Recording Frequency**	**Proportion of data**
1	Fuel Consumption per Batch	*Kg/batch (for Coal)*	Weighing, or reading of flow meter	Fuel	Batch wise	*100%*
2	Calorific Value of Fuel	*Kcal/Kg*	Measuring	Fuel Type	Regularly	Sample
3	Daily Brick Production	*No. of Bricks/Day*	Measuring	Kiln	Daily	100%
4	Weight of the bricks	*Kg/brick*	Measuring	Baked Brick	Regularly	Sample
5	Specific Energy Consumption	*KJ/ Brick*	Calculating	-----	Regularly	100%
6	Plant Operating Days	*No. of Days*	Measuring	------	Monthly	100%
7	Temperature of Flue Gases	^0C	Thermocouple	Stack/Flue Duct	Regularly	Batch Wise
8	Temperature of Bricks and Surfaces	^0C	K-Type Thermocouple/ Infrared Thermocouple	Inside the Kiln/Outside surface of kiln	Regularly	Batch Wise
9	Stack Flow	*m/s*	Pitot Tube	Stack	Regularly	Batch wise
10	O_2	*%*	Electrochemical	Stack/flue duct	Regularly	Batch wise
11	CO_2	*%*	Inferred from O_2	Stack/flue duct	Regularly	Batch wise
12	CO	*ppmv*	Electrochemical	Stack/flue duct	Regularly	Batch wise
13	SO_2	mg/Nm^3	Barium-Thorin titrimetic method	Stack	Regularly	Batch wise
14	NOx	mg/Nm^3	Gaseous sampling	Stack	Regularly	Batch wise
15	SPM	mg/Nm^3	Gravimetric	Dilute exhaust	Regularly	Batch wise

10 Thesis outcome:

Following outcomes are envisaged through various activities proposed under the research work:-

i. Enhancing awareness on energy efficient Brick Kiln for the production of efficient products.
ii. Improved knowledge on technology.
iii. Availability of energy efficient technology models.
iv. Improved capacity of brick kiln.
v. Alternative solution for brick manufacturing.
vi. Reduction of the Green house gas emissions from the brick kilns.
vii. Flexibility and simultaneously discreet in production process.
viii. Controlled monitoring resulting in a qualitative production.
ix. Low skilled labor intensive technology.
x. Cost effective due to moderate production rate.

11 Brief review of the work (National and International):

Brick and its manufacturing have a major contribution for the development of modern civilization. Clamp kiln' technology is the oldest form of brick burning method invented thousands of years ago and now almost obsolete. Gas fired Tunnel kiln is mostly used in developed countries while other semi-automated, labor-intensive, coal-based technologies like Tunnel, Habla Zig-zag, Vertical Shaft, Hoffman and Fixed Chimney kilns are visible in developing countries. Now there are about 125 billion bricks produced annually using automated kilns, which are about only 10% of the total production worldwide [7]. Due to technological advancement, leading brick companies in developed countries are replacing their age old tunnel kilns by new efficient burners and its accessories [8].

This review is going to provide an idea about the different brick kiln technologies in use.

Kiln Types:
Based on the manufacturing process and operational process, brick kilns are categorize on the basis of the method of production of draught (natural draught and forced draught kilns); or based on the direction of airflow in the kiln (up-draught, down-draught and cross draught kilns). From energy utilization viewpoint, it is best to classify brick kilns into:

a. **Intermittent Kilns:** Clamp Brick Kilns, Down Draught Kiln
b. **Continuous Kilns:** Bulls Trench, Fixed Chimney, High Draught, Hoffman and Tunnel Kilns

11.1 Intermittent Kilns:

In intermittent kilns, green bricks are fired in batches repeatedly; fire is allowed to die out and the bricks allowed cooling. In intermittent kilns, most of the heat contained in the hot flue gases, fired bricks, and the kiln structure is thus lost. Clamp, Scove, Scotch, and Downdraught kilns are examples of intermittent kilns. Intermittent kilns are very adaptable to changing market demands but not fuel efficient Such kilns are still widely used in several countries of Asia, Africa, and South and Central America.
In an intermittent kiln, the heat recovery from the hot exhaust gases is only partial, resulting in high exhaust gas losses. Thus, intermittent kilns, though being suitable for small-scale production, are not fuel efficient.

11.1.1 Clamp Brick Kilns:

Clamp brick kilns are most primitive type of brick kilns since no permanent kiln structure is built. It consists of essentially a pile of green bricks inter spread with combustibles material. Normally, the clay from which the bricks are molded also includes fuel material. The capacity of the clamp varies from 25,000 to 500,000 bricks. A flat dry area of land is first chosen and check work pattern of spread out, already burnt bricks were laid down in a desired length. Fuel in the form of cinder, coke or small pieces of coal is then spread between the check work bricks, covering the latter with a layer at least 20 cm thick. Dry green bricks are next closed - laid on edge upon this fuel bed. The height of the clamp is generally made up of approximately 20 to 30 layers of bricks. A thin layer of fuel is inter spread after every second layer of bricks, if the bricks don't contain fuel in the body. Its sides are sloped for stability. Three or four holes at the base of one of the clamp walls are provided in order to allow the initial ignition of the fuel bed. Two courses of already fired bricks are next laid on top of the green bricks for insulation purposes. Once a desired length of the clamp has been built up, the fuel bed may be ignited with wood stuffed into the fire holes of the clamp. The latter are bricked up with loosely placed burnt bricks once the flue bed is alight. As the fire advances, more green bricks are built into clamp. During burning, the heat rises through the bricks above and smoke leaves from the top of the clamp. The rate of burning is not controlled and depends on wind strength and direction. Once the fire has passed through a particular point, the bricks start to cool. They may be unloaded and sold. Fuel consumption in clamps is very high and at the same time the firing of bricks is not uniform.

11.1.2 Down Draught Kiln:

The down-draught kiln (DDK) is an intermittent kiln. In an intermittent kiln, one batch of bricks is fired at any given point of time. These are used not only for firing facing bricks but also roofing tiles, glazed tiles and refractory goods. These kilns may be either circular or rectangular with fire holes in the circular walls or in the two sidewalls. The size of the kilns varies considerably, capacities ranging from 10,000 to 100,000 bricks.

The kiln is first filled with green bricks. It is then fired and the batch is heated up to the maximum temperature and left to cool, before being drawn out from the kiln. In the process of heating, the kiln structure also gets heated-up, and while cooling, the stored heat in the structure is lost into the atmosphere. In these kilns the combustion gases from fire hole rise from behind the bag walls into the crown of the kiln and then descend through setting of bricks/ tiles to the openings in the kiln floor through which they pass into flues and then to the chimney.

Fuel consumption depends upon largely upon the conditions of the kiln, the manner of setting the bricks and the control of firing process. In a down-draught kiln, fuel is burnt in external fuel-boxes, provided on the outer periphery of the kiln. The hot gases from burning fuel rises to the roof of the kiln. Gases after being deflected from the roof, flow down through the brick setting and in the process warm and fire the bricks. The bricks rest either upon an open-work support of previously fired bricks or upon a perforated floor, through which the flue gases flow down into an underground channel which is connected to the chimney and are exhausted out of the kiln. The warm gases rising through the height of the chimney provide sufficient draught to pull the hot gases down continually through the stack of green bricks.
The loss of heat varies from one type of kiln to another. These kilns are comparatively much more efficient than the clamps.

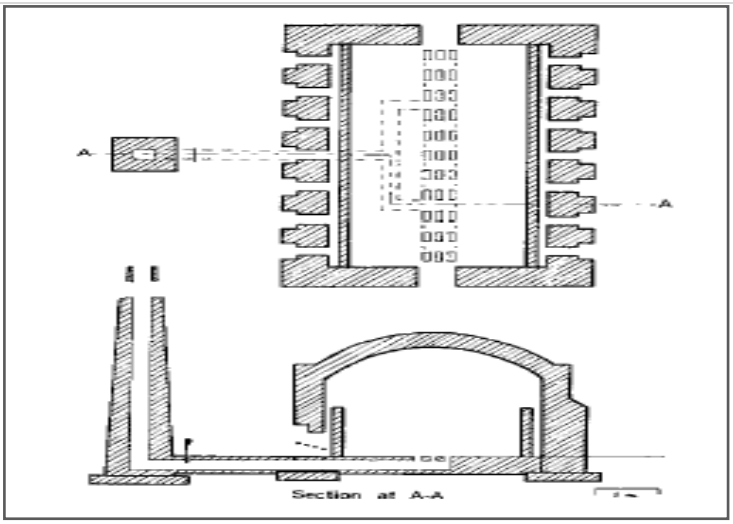

Figure-2: Sketch of a down-draught kiln

The average concentration of SPM in the kiln is near about 531 mg/Nm^3. The Indian emission tandard is 1200 mg/Nm^3 for small/medium/large categories of down draught kilns [10].

11.2 Continuous Kilns:

In a continuous kiln, on the other hand, fire is always burning and bricks are being warmed, fired, and cooled simultaneously in different parts of the kiln. Heat in the flue gas is utilized for heating and drying green bricks and the heat in the fired bricks is used for preheating air for combustion. Due to the incorporation of heat recovery features, continuous kilns are more energy efficient.
Such kilns can be further sub-divided into two categories:-

i. Moving fire kilns (Bulls Trench, Fixed Chimney, High Draught, Hoffman)and
ii. Moving ware kilns (Tunnel Kilns).

i. In a moving-fire kiln, the fire progressively moves round a closed kiln circuit while the bricks remain stationary. The kiln circuit can have oval, rectangular or circular shapes. FCBTK and Zig-zag kilns are types of moving-fire kilns.

ii. In a moving ware kiln, the fire remains stationary, while the bricks and air move in counter-current paths. In a tunnel kiln, which is a horizontal moving ware kiln, goods to be fired are passed on cars through a long horizontal tunnel. A vertical shaft brick kiln is another example of a moving ware kiln. In this kiln the movement of bricks is in a vertical downward direction, and upward air movement is brought about by natural convection.

11.2.1 Moving Chimney BTK to Fixed Chimney BTK:

In the early 1990s, about 30,000 moving chimney BTKs were operational in India. In 1996, based on the recommendations of COINDS (Comprehensive Industry Document Series) study, the MoEF issued a notification banning all types of moving chimney BTKs and ordering all the moving chimney kilns to convert to fi xed chimney by June 2002. The Central Building Research Institute (CBRI), the Aligarh Muslim University (AMU), and the Punjab State Council for Science and Technology (PSCST) developed designs for chimneys equipped with gravity settling chambers. By 2002, about 75% of the moving chimney BTKs shifted to fixed chimney BTKs.The conversion not only helped in the reduction in SPM emissions but also resulted in fuel savings (about 10%–15%) and increased production and better quality [11].

11.2.2 Fixed Chimney Kiln:

A FCBTK is a continuous, cross-draught, annular, moving fire kiln operated under a natural draught, which is provided by a chimney. FCK is rectangular in shape and measures around 80 m long and 20 m wide. Its origin lies in the Hoffman kiln, which was patented in 1858. A British engineer, W. Bull is credited with introducing the Bull's Trench Kiln (BTK) to India in 1876. It is a moving fire kiln, in which the fire moves through the bricks, which are stacked in the annular space formed between the outer and the inner wall of the kiln. Green bricks are loaded in front of the firing zone, and cooled fired bricks are removed from behind. The kiln is generally of oval or circular shape.

FCK is a modified version of the previously used Bull's Trench Kiln (BTK) which had a low-height movable metallic chimney. BTK was more polluting than the present FCK as the chimney height was considerably low. FCK is usually constructed on low lying ground, sometimes partially under the ground. The tall fixed chimneys as shown in Figure-2 of these kilns create a strong draft and release flue gas at a height of 40 m above the ground, providing faster and better dispersion than previous low height chimneys of BTKs. FCKs are integrated with underground pipes/ducts to collect flue gases from anywhere in the kiln to the fixed chimney. The width of the fixed chimney is selected in such a predefined way to accommodate all the flue gas collecting ducts. The cost of constructing the chimney is nearly 50% of the total cost of the kiln [12]. Green bricks are stacked at one end which is known as the preheating zone and fired bricks are taken out from the other end which is known as the cooling zone.
Fuel (coal) is charged from the top in between these two zones which is known as the firing zone. The burning of coal in FCK is not efficient by any means. Thick black smoke emits from the chimney due to inefficient manual coal charging. Between two coal charging, flue gas color changes from grayish black to milky white and remains white until the next coal is charged. So the pollutants visible are actually fly ash and un-burnt carbon particles. Existence of un-burnt carbon particles in the flue gas results from excess coal charging compared to air supply to complete the combustion in the firing zone. Light fine coal particles become airborne to escape from the firing zone and reach the pre-heating zone (colder) where it is impossible to get burnt. Larger coal particles get deposited on stacked bricks, where it slowly burns out to leave ash on the brick surfaces. Expert firemen are essential for effective control of combustion. A frequent changing of smaller quantity coal is better for consistent burning, which in turn releases a much less pollution into the atmosphere. Also, high quality coal is essential to release less pollution.

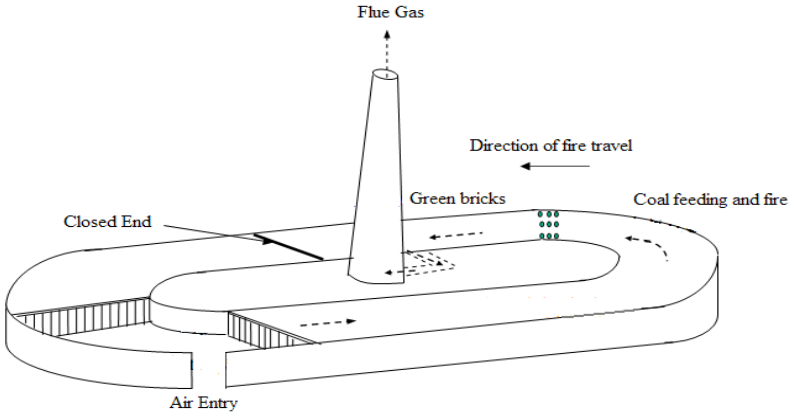

Figure-3: Fixed Chimney Kiln

The SEC for the three FCBTK is in the range of 1.10-1.46 MJ/Kg of fired bricks [13, 14]. Average SPM concentration of the three monitored FCBTKs ranged between 143 mg/Nm3 to 800 mg/Nm^3 [15, 16, 17].

11.2.3 High Draught Kiln (Zig- zag Kiln):

The main innovation was the Zig-zag path to increase the length of the firing channel and accelerate the firing through a flue gas fan. Zig-zag kilns were widely used in Germany between the first and Second World Wars. They were also popular in Australia. The Zig-zag kiln was introduced in India by the Central Building Research Institute during the early 1970's in the form of a high draught kiln.

Zig-zag kiln has some similarity with FCK. It is rectangular in shape and measures 80 m by 25 m [18] as shown in Figure-3. It has an 18 m high fixed chimney located on one side of the kiln. A typical Habla Zigzag kiln is shown in Figure 2.7. At the bottom of the chimney there is a blower, which draws flue gas from the kiln and discharges into the atmosphere. This kiln is divided into 20 to 40 chambers by green brick stacks, which are separated from each other in such a way that the hot gases move in a zigzag path through the kiln [19]. So the length of airflow inside the kiln is increased by zigzagging of the chambers. Likewise fire follows a zigzag path instead of the straight path practiced in BTK or FCK. In the long travel path of the hot gas, the green bricks absorb much of the waste heat to have better drying and moisture reduction. Based on various studies, Zig-zag Kiln is considered to be 10-15% more fuel efficient than the FCK [12].

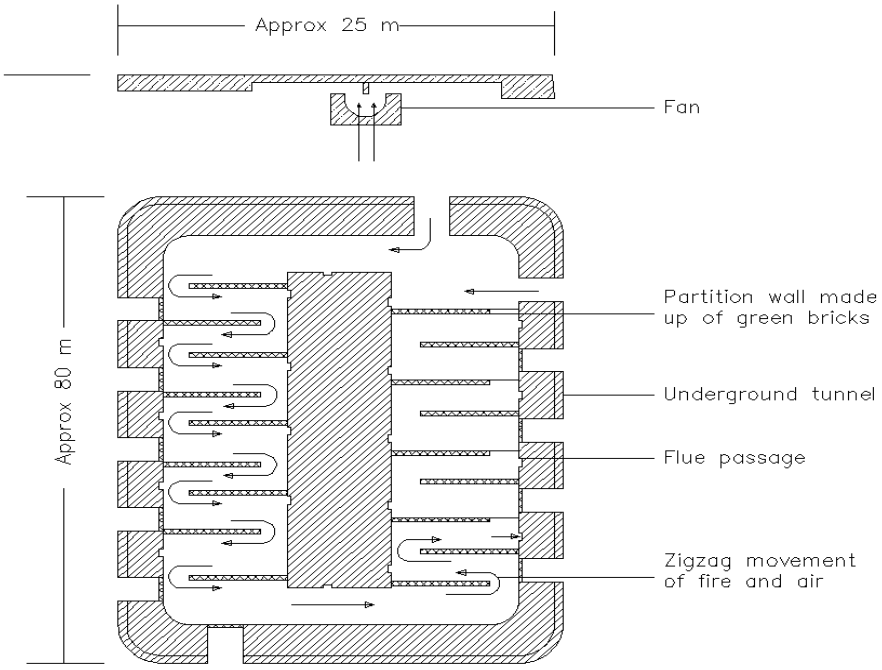

Figure-4: Schematic view of a Habla Zig-zag kiln

The repeated changes of flue gas direction and impacts on the walls and green brick stacks, lead to the deposition of significant amount of particles and carbons on the floor. This is the reason why Zig-zag kiln produces less emission than FCK. Zigzag also incorporates flue gas scrubber, where the connecting duct between the center of the kiln and the inlet of the draft fan is half to two-third full with water. Flue gas impinges on water to lose some of its particulates further.

Zig-zag kiln construction cost is approximately the same as that of FCK [12]. As this technology is quite similar to FCK and the conversion expenditure is relatively low. Qualitative evaluation on poorly managed Zigzag kilns indicate that these are as polluting as the FCKs, while the better managed kilns produce about half of the FCKs pollution [20]. An improved Zigzag kiln with a standard design leads to lower emission and increased energy efficiency [7]. It includes improvements such as use of internal fuel by mixing pulverized coal into the clay to form green bricks, better insulation with reduced heat loss and better flue

gas scrubber. The use of internal fuel can rise up to 80% of the total fuel requirement, while the remaining 20% is destined to produce much less emission. The current FCKs can also be converted into Zigzags by retaining FCK's tall chimney in place [9]. The requirement of an electricity supply 24/7 for the continuous operation of a forced draught Zig-zag kiln is an important barrier to wide scale adoption. In recent years, some of the brick makers have modified the brick setting and practices and have successfully operated the kiln with natural draught.

Table-3: Comparison between natural draught Zig-zag and forced draught Zig-zag kilns

Natural draught Zig-zag	*Forced draught Zig-zag*
1. Draught is created naturally with the help of a chimney. 2. Operates under a negative pressure of 8 – 10 mm water column. 3. Brick setting is less dense to reduce pressure drop so as to operate with natural draught. 4. Height of Chimney is around 120 – 130 ft. 5. No electricity/diesel is required for operation of the kiln.	1. Draught is created artificially with the help of a fan. 2. Operates under a negative pressure of around 50 mm water column. 3. Brick setting is very dense. 4. Height of the chimney is around 55 – 60 ft. 5. Electricity /Diesel is required for operation of the kiln.

There is not much information available on the emission characteristics of Zig-zag kilns. The only reported results are from a study by Teri (1998) [24] which had reported SPM emission level of 14-37 mg/Nm^3 for a natural draught Zig-zag kiln and 151 mg/Nm^3 for a forced draught Zig-zag kiln.

11.2.4 Hoffman Kiln:

Hoffman kiln is generally used for firing roofing tiles. The kiln was developed in Germany in 1858. Hoffman is a gas-fired kiln, has quite similar construction and operation procedure as that of FCK. The significant difference is - it has a fixed roof as shown in Figure- 4, whereas FCK has a temporary roof. Due to this fixed roof, bricks can be fired throughout the year in Hoffman kiln. A typical Hoffman kiln is around 100-130 m by 20 m [18]. Although this kiln should run throughout the year, in practice, during monsoon the number of bricks produced decreases significantly due to rainfall. Increased humidity and absence of adequate sunlight also contributes to this decreased production. Often manufacturers tend to overproduce bricks to sell during the rainy season, raising the requirement of adequate storage facility to stock large number of finished bricks. In countries where there are long rainy season occurs, not only bricks but also raw materials including clay have to be stored.

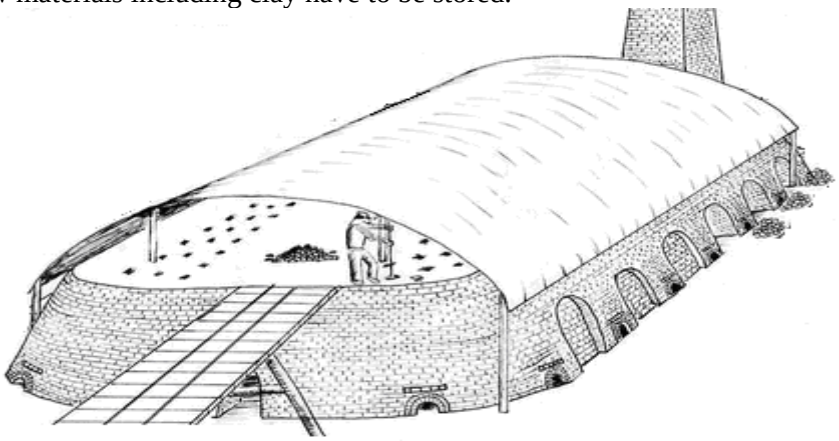

Figure - 5: Schematic view of a Hoffman kiln (Kynaston 1984)

Because of the thick wall and effective insulation, heat loss becomes minimized to its surrounding. The brick stacking technique is similar as that of FCK as shown in Figure-4. Pipe type burners are inserted

from the top to supply fuel (natural gas) to the combustion chamber where bricks are burnt. Burners are shifted forward through holes at the top of the kiln when burning of a particular batch is complete. Fired bricks are unloaded from one end and green bricks are stacked to the front.
Controlling the fire is the trickiest part of the whole operation. In most of the kilns there is no fire controlling instrument. So the fire master based on his experience changes gas flow rate and alters opening and closing of dampers, located at selected points of flue gas network, to control fire. Several years on job training is required for a person to become a master of fire. In Hoffman brick kiln, gas is used as fuel. Usually gas fired kilns provide better colored bricks. In developing countries, there is a wrong perception that bricks with bright color are strong. However, quality of bricks can only be determined by their compressive strength and water absorption capacity

11.2.5 Coal based Hoffman kiln

Hoffman kiln also uses coal instead of gas as fuel as shown in Figure-5. Some modification is done in kiln design by diverting flue gas through green bricks before stacking those inside the kiln. Countries with lacking or inadequate gas, people prefer coal based kiln over gas based kiln. However coal based Hoffman kiln generates more pollution than gas based one [22]. Useful life of this type of kiln, with proper annual maintenance, is at least 10 years [12].

Figure - 6: Workers pouring pulverized coal for combustion through holes at the roof

11.2.6 Vertical Shaft Brick kiln (VSBK):

Vertical Shaft Brick kiln (VSBK) was first developed in China and is very popular in rural areas for small-scale production. The evolution and initial development of the Vertical Shaft Brick Kiln (VSBK) technology took place in rural China. The first version of VSBK in China originated from the traditional updraft intermittent kiln during the 1960's. In the next decade, the kiln became popular in several provinces. In 1985, the Chinese government commissioned the Energy Research Institute of the Henan Academy of Sciences at Zhengzhou, Henan, to study the kiln and improve its energy efficiency. The institute came up with an improved design of VSBK in 1988. The improved design had a higher shaft height and also a provision for a pair of chimneys. In 1996, several thousand VSBKs were reported to be operating in China. Since then the technology has been transferred (under various development projects) to several countries, including India, Nepal, Afghanistan, Vietnam, Pakistan, Sudan, and South Africa. Among these countries the technology has gained wide-spread popularity in Vietnam only; in other countries the dissemination of the VSBK technology is still limited to a small number of enterprises.
In addition, the kiln is simple to construct and operate round the year, making it ideal for rural areas. It showed limited success in India and Nepal. Compared to FCK, VSBK uses less energy and emits less pollution [23]. However, brick quality of VSBK is relatively poor compared to its incremental investment.

In VSBK, there is a vertical shaft of rectangular or square cross-section, as shown in Figure-6. Green bricks are loaded in batches from the top. Bricks move down the shaft as it goes through preheating, firing and cooling zones and finally unloaded at the bottom. Combustion of fuel (coal) takes place in the middle of the shaft. Air enters at the bottom and flows through the burnt bricks, cools it and then passes through the combustion zone at the middle where it reacts with coal and finally releases some of its energy obtained in the combustion zone by preheating green bricks. So, counter current heat exchange occurs inside the kiln.

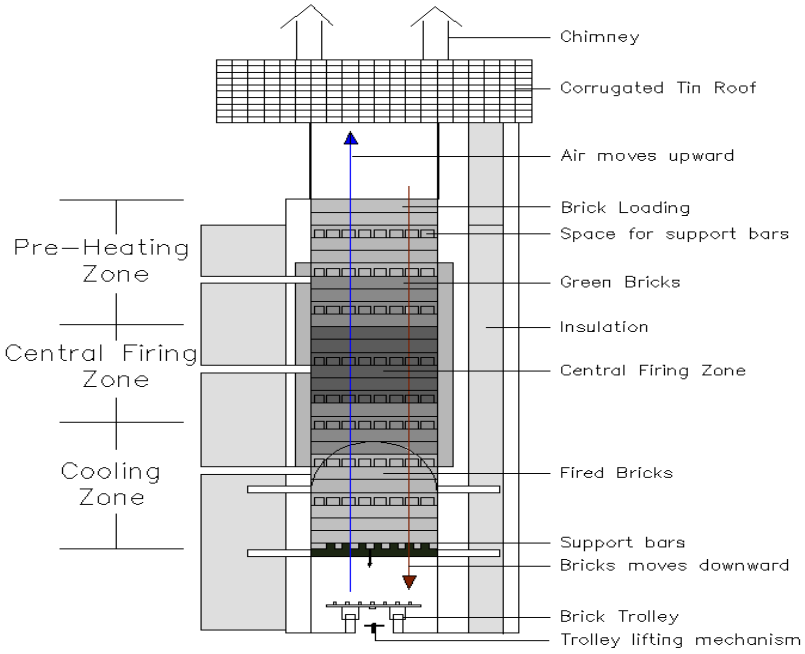

Figure - 7: Schematic view of a VSBK

Unlike FCK, VSBK has a permanent structure and can produce bricks throughout the year. It has a design life of 8 to 10 years with minimum maintenance requirement [31]. The greatest benefit of VSBK is, as the kiln constructed vertically, it is very economical in utilizing space. In VSBK, pulverized coal up to 50% of the total fuel demand can be mixed with clay as internal fuel. The rest of the coal is charged along with the green bricks in the loading process. The charged coal that enters the firing zone slowly tends to burn completely and thus providing a higher efficiency and less pollution. This is a contrast in comparison to other coal fired kilns, where coal is charged in a regular interval. Operation of VSBK requires more skilled labor. Brick unloading can be a challenge because bricks tend to crack if withdrawn quickly from the hot kiln. However, VSBK bricks satisfy typical standard related to compressive strength and water absorbency despite its dull color compared to FCK bricks.

The Indian emission standard of 250 mg/Nm^3 prescribed by the MoEF for small, medium, and large category VSBK [24]. The average concentration of SPM in the kiln was 114 mg/Nm^3. SPM values are between 77 to 250 mg/Nm^3 of for VSBKs as monitored in India by TERI [25].

11.2.7 Tunnel kiln:

Tunnel kilns are widely used in brick and particularly in ceramic manufacturing industries. It is an elongated kiln, which looks like a tunnel and is made of refractory and heat insulated construction material. Inside the kiln, kiln cars transport the green wares and eventually the final products. It has typical

length between 35 m and 250 m, width between 1 m and 6 m and height between 1 m and 2 m [26].

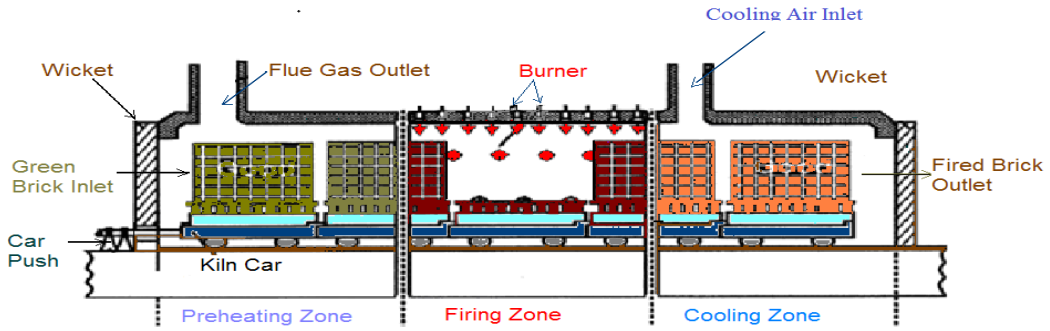

Figure - 8: Tunnel kiln

Tunnel kilns are continuously operated kilns that receive bricks on track-mounted cars called kiln cars. These cars are fed into the kiln, one after another, and are pulled through the kiln's different drying and firing zones. In Tunnel kiln, green bricks are exposed to a sequence of heat treatment cycles, moving slowly through various temperature zones over the kiln cars. These cars are put on the tracks and enter the drying portion of the kiln in separate chamber where they remain for about 48 hours to reduce the moisture content. Preheated green wares then enters into the kiln from one end of the kiln, increase in temperature and undergoing of the sintering. During sintering the atoms in the green brick diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece. The green wares become products and move out of the kiln from the other end. In the firing zone of the kiln, the temperature is usually between 850oC and 1250oC which needs to vary with the type of brick. In the preheating and firing zones, the heat from the high temperature flue gas preheats the green ware. Therefore the green ware temperature increases and the flue gas temperature decreases. After the removal of all the products the empty kiln car is going to the other side of the kiln, to begin the next production cycle. Usually 40 to 80 kiln cars remain at a time inside the Tunnel kiln [27]. To complete a full cycle of brick burning inside the Tunnel kiln it requires 36 to 72 hours to achieve different quality bricks and ceramics.

The traditional Tunnel kiln suffers from long production cycle, high energy intensity, relatively high rejection rates (~10%), and low levels of automation – in many phases of the traditional process, bricks are moved and stacked manually. However, Tunnel kiln is the most modern brick kiln, has scope for high automation. Both coal and gas can be used as fuel. Though it produces the best quality bricks but the cost is higher compared to other brick kilns. Since 1947, Tunnel kilns are gradually replacing circular intermittent kilns. In recent years, Tunnel kiln has become the most popular and commonly used kiln in developed countries as this kiln is highly automated and requires less manpower.

The layout of a typical Tunnel kiln is shown in Figure-8, where the three temperature zones as shown are: preheating, firing and cooling. The SPM concentration emission standard is 400 mg/Nm^3 [28].

11.3 Distribution of different Kilns in India:

Brief details of the brick making process and the types of brick kilns are provided in Table-3.The brick industry in the Gangetic Plains differs from the brick industry in peninsular and coastal India. The Gangetic Plains of North India account for about 65% of total brick production. Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are the major brick producing states in this region. Brick kilns, generally of medium and large production capacities (2–10 million bricks per year), are located in clusters around major towns and cities. Coal is the main fuel used for firing bricks.

The availability of fertile alluvium soils in North India has caused the fringe areas of cities in this region to be dotted with brick kilns and consequently is a significant force in bringing about land use/ land cover changes around cities [29]. Peninsular and coastal India account for the remaining 35% of brick production. In this region, bricks are produced in numerous small units (production capacities generally range from 0.1 to 3 million bricks per year). Gujarat, Orissa, Madhya Pradesh, Maharashtra, and Tamil Nadu are important brick producing states in the peninsular plateau and coastal India. Apart from coal, a variety of biomass fuels such as firewood, dry dung and rice husk are also used for firing bricks.

Table-4: Brick kiln technologies currently prevalent in India

Kiln Type	Regional spread	Approximate contribution in brick production
Clamps	Central, West and Southern India	25%
Fixed chimney BTK	Indo-Gangetic plains (North and East India) and several clusters in South and West India	70%
Zig-zag	West Bengal, a few clusters in North India	2-3%
VSBK	Central India	1-2%

Table-3 provides the details about the various types of firing technology currently prevalent in India. Currently, Fixed Chimney Bull's Trench Kiln (FCBTK) is the leading technology for firing bricks. FCBTK accounts for around 70% of the total brick production in India and is prevalent in the Indo-Gangetic plains, as well as in some pockets in the rest of the country. Clamps are used widely all over peninsular India. Down-draught kilns, Vertical Shaft Brick Kilns (VSBK), Hoffmann kilns, and Zig-zag fired kilns make up less than 5% of all kilns.

11.4 Comparative overview of different brick kiln technologies:

This section compares different aspects of brick production from collecting raw materials to making finished product of Fixed Chimney Kiln (FCK), Zigzag kiln, Coal based Hoffmann kiln (HK) and Vertical Shaft Brick kiln (VSBK) are described in the following paragraphs.

11.4.1 Land requirement:

Land requirement for a FCK or a Zigzag is about 3-4 acres whereas that for a coal based Hoffmann Kiln (HK) is about 12 acres [30]. Higher land requirement for coal based HK also ensures greater production capacity. Major part of the land requirement is needed for brick molding, drying and other brick processing operations. If only the kiln portion is compared then the land requirement for coal based HK is less than half compared to FCK. For VSBK, land requirement is less than one-fourth of FCK for same amount of production [23]. The high variation of cost for different category lands has made this a vital issue for entrepreneurs for selecting the type of kiln.

11.4.2 Fuel requirement:

Coal is the only option for brick industries in countries where natural gas is low in supply. Those previously constructed Hoffman kilns are barely using natural gas as fuel and the consumption rate is 15,000-17,000 m3 per 100,000 bricks [12]. Considering energy consumption requirement, coal based HK is more efficient than FCKs and Zigzag kilns. The coal requirement for FCK is around 24 ton per 100,000 brick production [20]. Zigzag kiln and coal based HK consume around 18 and 14 ton coal per 100,000 brick production, respectively [18]. VSBK is the most fuel-efficient, consuming least fuel around 10 ton of coal for 100,000 bricks [23].

11.4.3 Brick quality:

Hoffman kilns produce better colored bricks because of gas burning. Bricks from coal based HK have also good color and shape and duly get higher price in the market. VSBK cannot produce very good quality bricks as green bricks cannot be fired for long time inside the kiln. Vertical structure of this kiln may cause load variance resulting cracks in bricks if fired for a long time. So, strong bricks which are locally known as “pickets” and used instead of stone for concreting cannot be produced by VSBK. Bricks from Zigzag and FCK are of same average quality generally produced.

11.4.4 Investment opportunity:

In terms of initial investment, FCK, Zigzag or VSBK require expenditure in the range of US$ 50,000 to 70,000 [31]. The conversion of FCK to Zigzag requires only US$ 30,000 and thus not much burden and uncertainty to future business and return. Hoffmann kiln is quite expensive requiring an initial investment of at least US$ 600,000. Coal based HK also requires an initial investment of about US$ 600,000 to 700,000 [12]. One major reason for the cost-variance between coal based HK and Hoffmann is, in coal based HK an additional drier is required to dry the green bricks by utilizing the waste heat of the flue gases. This modification also reduces pollution to some extent. Similar modification could be done for gas-fueled Hoffmann but due to its low pollution level, this modification can be considered superfluous unless otherwise justified by economic analysis. These kilns can operate round the year. Building Hoffmann kiln requires special expertise and thus demands high skill engineering consultants. Working capital requirement for FCK and Zigzag kilns is approximately US$ 20,000 to 22,000 but for a Hoffmann it can go beyond US$ 100,000 because of higher inventory, maintenance and overhead costs [18].

11.4.5 Production rate:

Hoffmann kiln has a production capacity of 7.5 to 9 million bricks per season [31]. Coal based HK has a production capacity of around 15 million bricks as preheated and dehydrated green bricks require less time for burning [18] FCK and Zigzag have approximately the same production capacity of around 2.5 million bricks per season as both the kilns are usually built in the low-lying land [18] An ordinary VSBK has a production capacity of 2.7 million bricks and can operate all-round the year [31]. The production capacity of VSBK can be increased several times simply by increasing the number of kiln shaft. To visualize the characteristics of the above comparative analysis easily, a number of mentioned factors are shown in Table- 4 below.

11.4.6 Emission:

One of the major reasons of pollution from brick kilns is inadequate supply of air during combustion. Blowers are added to Zigzag and coal based HK to ensure enough air supply to kilns. In VSBK, air flows upward through natural convection. In Zig-zag kiln, as air flows through the zigzag path, the coarse particles are obstructed and settle before it is discharged into the atmosphere. The combustion process improves as artificial draft is created by the addition of blower. Also scrubbers are used to remove fly ash and SOx in the Zig-zag kiln. In a scrubber, flue gas is drawn into an underground water reservoir to clear solid particles before being released into the atmosphere. Scrubbing water has to be changed regularly to ensure the system works properly. However, brickfield owners often do not care as it requires additional workforce, unless otherwise monitored regularly by the government agency.

Hoffmann kiln shows better performance than other coal burning technologies in terms of pollution control. For coal based Hoffmann, flue gases are passed through dryer to preheat the green bricks. Hard particles clear up largely from the flue gas since it is obstructed into the stacks of green bricks. VSBK requires less fuel per brick basis, so automatically emits less.

Theoretically there should not be much black smoke from VSBK but sometime due to un-burnt combustion, black smoke emits. Carbon dioxide emission from all four types of brick kilns is shown in Table-4 for comparison. Detailed computation is shown in Table-5. From this table, it is clear that VSBK emits least CO_2 followed by coal based HK and Zigzag than FCK.

Table-5: Comparison of various key factors for different brick kilns

Item	FCK	HK (coal)	Zigzag	VSBK
Land Requirement	16,000 m2	50,000 m2	16,000 m2	4,000 m2
Brick shape and color quality	Medium	Higher-medium	Medium	Low
Investment requirement (US$)	55,000	700,000	70,000	70,000
Working capital (US$)	22,000	100,000	22,000	22,000
Production rate/day	17,000	50,000	17,000	9,000
Production days/year	150	300	150	300
Coal required per 100.000 bricks	24 ton	14 ton	18 ton	10 ton

Table-6: CO2 emission comparison from different brick kilns

Item	FCK	HK (coal)	Zigzag	VSBK
Specific fuel consumption (TJ/brick)	$4.02 \times 10\text{-}^{6}$	2.35×10^{-6}	$3.02 \times 10\text{-}^{6}$	1.68×10^{-6}
CO2 emission per 100,000 bricks (ton of CO2)	38.06	22.20	28.54	15.86

From the above literature review it is clear that the Vertical Shaft Brick Kiln (VSBK) is the best in terms of the energy consumption. But it is also clear from the Table-3 that its contribution in the Indian brick sector is only 1-2%. The main reason behind this is the low production capacity (9,000 Bricks) per day, highly skilled labor requirement and low quality of the shape and color. So due to low quantity and quality of production it is not viable with respect to the existing FCK which has a major contribution upto 70% in this industry.

Considering the above review there is a need of such technology which could be able to reduce energy consumption, and reduce GHG emissions. So there is a need to carry out a comprehensive assessment of brick making technologies to gain a deeper understanding of the energy utilization and emissions from current technologies as well as technologies that offer the promise of cleaner brick production. It is also required to carry out a brief study of natural gas bases tunnel Type brick kiln for small scale production having the production capacity upto 20,000- 25000 Bricks per day and low initial investment.

12 Schedule of activity:

- **a.** Literature survey (3 months)
- **b.** Identification of the location (Cluster near the Agra Region-TTZ) and perform the study of different given parameters of the brick kilns which are operating with coal and other bio fuels. (3 months)
- **c.** Development a model Natural gas based Tunnel type kiln.(6 months)
- **d.** Experimental investigation of Kiln performance using Natural gas as a fuel.(3 months)
- **e.** Comparative study and analysis of the kiln performance using the natural gas as a fuel. (6 months)
- **f.** Analysis of the results on the basis of the energy and green house gas emissions. (3 months)
- **g.** Impact of the result obtains on the Kiln Industry and environment. (3 months)
- **h.** Conclusion(2 months)
- **i.** Thesis writing(6 Months)

13 Impact of proposed research work in academic/industry:

Government regulations and other developmental efforts by different agencies have so far had limited impacts on the Indian brick industry both on the production technology and types of bricks produced.

With the construction sector in India growing at about 9%, the demand for various resources required for brick making will also increase substantially under business as usual scenario. Coupled with escalating costs of energy and depleting resources, it is paramount for the brick industry to adopt energy-efficient processes and products to alter the present conditions.

Technology upgradation in the small scale brick sector would lead to modernization of the industry. It would promote usage of machinery such as brick extruders for production of energy – efficient bricks in the industry. Currently the brick production process is very traditional and artisanal and bricks are mainly produced through manual processes. Brick making is a traditional industry with little knowledge on raw material (mainly clay) and its selection. Sun drying of bricks is done in Indian brick industries and introduction of machinery would require better understanding on the drying processes. Upgradation of equipment/ systems for producing energy–efficient bricks would require better and improved understanding and knowledge on various aspects of raw materials and its preparation.

Significant knowledge and skills at various levels of the industry (workers, operators and entrepreneurs) are required for improving yield and reducing breakage in brick making. Technology upgradation in the sector would open up new sets of opportunities of employment in the brick sector which would lead to improved livelihoods for the workers.

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